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Application of Multi-Sensors Information Fusion for Self-protection System of Robot

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Abstract

This paper developed a kind of robot self-protection system using the multi-sensors information fusion technology. This system used five groups of photoelectric sensor and ultrasonic sensor which were installed in different direction of the robot. In this study, signals were gathered by using the complement of ranging of photoelectric sensor and ultrasonic sensor. Then the signals were sent to MCU to achieve multi-sensors information fusion. Core fusion technology was the adaptive weighted fusion estimation algorithm, which can make measurement data more accurate. With such technology, an accurate robot self-protection command was made as to avoid obstacles, to judge narrow highland and to prevent dropping. The experiment results validated its good self-protection function.

Keywords*: multi-sensors information fusion, adaptive weighted fusion estimation algorithm, self-protection system*

1. Introduction

Modern robots are often used in places where people cannot reach or in areas of high risk, high levels of pollution and war. So before the robot completes the task, it is necessary to guarantee the safety of the robot itself. Renowned science writer Isaac Asimov presents Three Laws of Robotics, which stress that "A robot must protect its own existence" [1].

To make the robot take protective action intelligently, first of all, the designer must make sure that the robot have the ability to perceive environment and to collect environmental information. Second, the existing information should be effectively integrated and be made full use of. But the current conventional method is to realize independently with a single sensor or to combine different types of sensors simply [2]. These sensors can not be analized as a whole. The shortcomings of such realization method are the followings: Firstly, workload of information processing is increased, and the inner link of information on the sensors is split, which will result in occupying more microprocessor resources. Secondly, each function is not use jointly, and sometimes there will be a misjudgment. This study emphasizes the complement of multi-sensors and the fusion of multi-sensors information. This paper puts forward the concept of the multi-sensors system [2], so as to control the robot work intelligently.

2. Hardware Structure of Multi-sensors System

The robot in this study is a kind of intelligent robot, which can combine photoelectric sensor with ultrasonic sensor [3] and use MCU STC89C58RD+ as the core control. This robot have the basic self-protection functions, including to avoid obstacles, to judge narrow highland and to prevent dropping.

The whole self-protection system has an installation of five photoelectric sensors and five ultrasonic sensors, namely on the same installation position, a photoelectric sensor and an ultrasonic sensor are installed, and the specific installation position is shown in Figure1. The model of photoelectric sensor is ODSL25, its measuring range is 0.5-30cm, the model of ultrasonic sensor is 23A25T/R, the measuring range is 30-400cm. Four groups of sensors are respectively installed downward in front of and rear part of robot track wheels. And one group of sensors are installed forward on the robot head. Photoelectric sensor is mainly responsible for signal collection of near obstacles (less than 30cm), while the ultrasonic sensor is mainly

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responsible for signal collection of far obstacles (more than 30cm). Obstacle avoidance distance and highland initial parameters can be set by keying. All the collected signals are sent to the MCU to be confused. Finally, the MCU command the robot to take protective action. Multi-sensors system hardware system is shown in Figure 2.

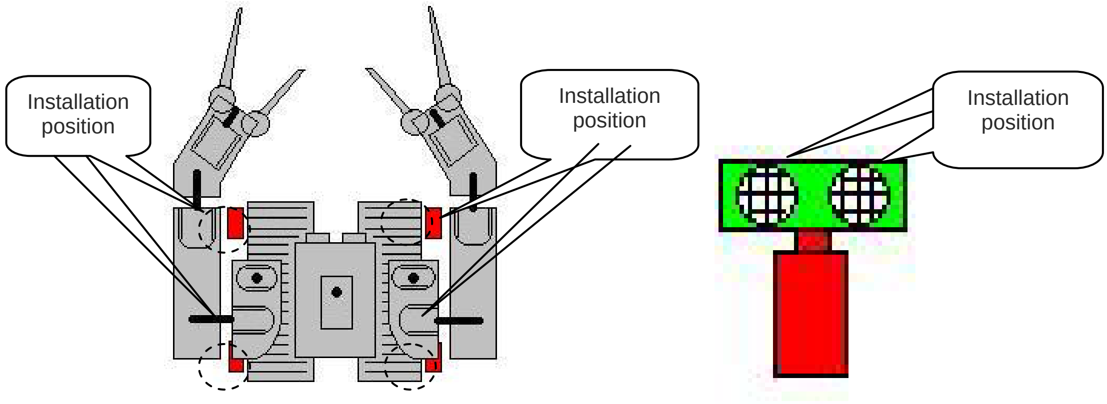

Figure 1. Photoelectric sensors and ultrasonic sensors installation position

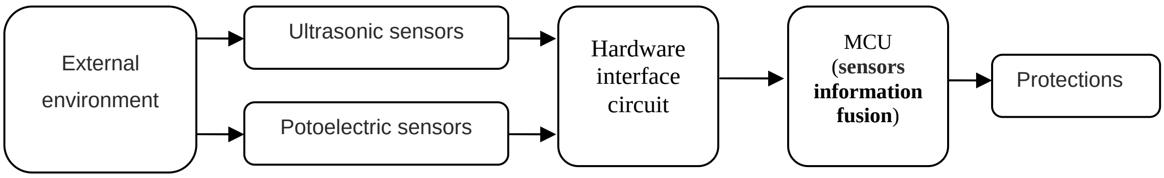

Figure 2. Hardware structure of multi-sensors system

The output signal from these sensors must go through some of the treatments before put into the MCU to be processed. For example, the output signal of ultrasonic sensors in this system is so weak, and mixed much interference that MCU can not recognize it. The signal must be amplified and filtered before it was sent to the MCU. The output signals of photoelectric sensor in this system is weak analog signal, which can be sent into the MCU through amplification circuit and A/D converting circuit.

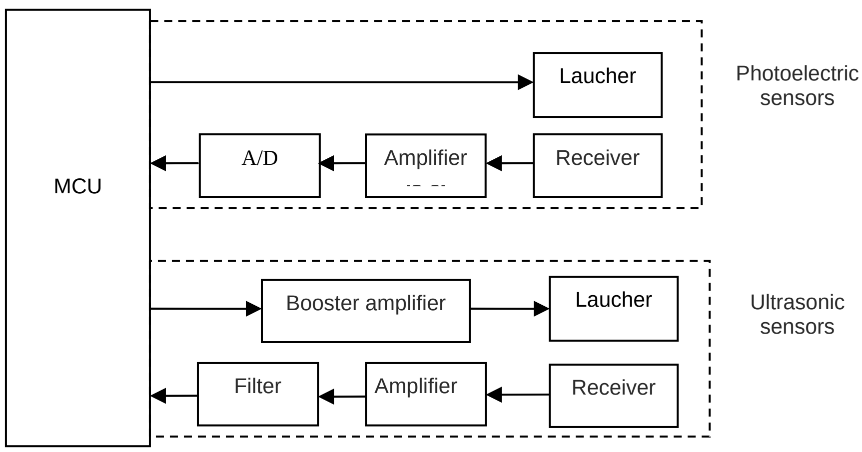

Figure 3. The hardware interface circuit diagram between sensors and MCU

At the same time in order to improve the measuring precision of sensor, the single sent to sensor by the MCU also needs some processing.For example, in order to improve the measurement precision of ultrasonic sensor, in addition to the using of the appropriate frequency and wavelength, improving the sensor voltage is another effective method to improve the accuracy of ultrasonic sensor [4]. So in this system, the excitation signal of MCU went through a amplifying circuit. Specific sensor and MCU interface circuit are shown in Figure 3.

3. Software System of Multi-Sensors System

If the multi-sensors system is equivalent to self-protection hardware system, the multi-sensors fusion technology is the software system which can run the protection program.

3.1. Information Fusion Algorithm

The information processed by the interface circuit will be sent to the MCU for data fusion.The adaptive weighted fusion estimation algorithm was adopted for information fusion in this part, and was realized mainly through the software programming.Then MCU according to the fusion information gave the corresponding orders of self-protection to the robot. The introduction of the algorithm is shown as follows Equations [5].

The whole algorithm design ideas: the auto-covariance and the cross-covariance are solved by using Eq. 1 and Eq. 2 and the cross-covariance need to replace by estimate value using Eq. 3. Then find out the variance (Eq.4) of ultrasonic and photoelectric sensor. Using the data above, the optimal weighted factor and the mean for the moment n was solved using the Eq. 5- Eq. 8 after fusion of mean calculation. Finally the mean after fusion was getten using Eq. 9 and returned it to main program.

$$C_{pp}(n) = \frac{n-1}{n} C_{pp}(n-1) + \frac{1}{n} X_p(n) X_p(n), \tag{1}$$

$$C_{pq}(n) = \frac{n-1}{n} C_{pq}(n-1) + \frac{1}{n} X_p(n) X_p(n), \tag{2}$$

$$C_{pq} = \overline{C_{pq}}(n) = \frac{1}{n-1} \sum_{q=1, p \neq q}^{n} C_{pq}(n), \tag{3}$$

$$\sigma_p^2 = E[V_p^2] = C_{pp} - C_{pq}, \tag{4}$$

$$W_p^* = 1 \Big/ \left(\sigma_p^2 \sum_{i=1}^{m} \frac{1}{\sigma_i^2}\right) \quad \text{(p=1,2,3…,m)}, \tag{5}$$

$$W_q^* = 1 \Big/ \left(\sigma_q^2 \sum_{i=1}^{m} \frac{1}{\sigma_i^2}\right) \quad \text{(q=1,2,3…,m)}, \tag{6}$$

$$\overline{X}_p(n) = \frac{1}{n} \sum_{i=1}^{n} X_p(i) = \frac{n-1}{n} \overline{X}_p(n-1) + \frac{1}{n} X_p(n), \tag{7}$$

$$\overline{X}_q(n) = \frac{1}{n} \sum_{i=1}^{n} X_q(i) = \frac{n-1}{n} \overline{X}_q(n-1) + \frac{1}{n} X_q(n), \tag{8}$$

$$\overline{X} = W^{*}_{p}\overline{X}_{p}(n) + W^{*}_{q}\overline{X}_{q}(n) \ , \qquad (9)$$

where $C_{pp}(n)$ is the auto-covariance of ultrasonic sensor p for the moment n, $C_{pq}(n)$ is the cross-covariance of ultrasonic sensor p and the photoelectric sensor q for the moment n. And $X_{p}(i)$ is the measured value of the i time of ultrasonic sensor p. $\overline{C}_{pq}(n)$ is the mean of cross-covariance $C_{pq}(n)$ for the moment n , as the estimate of cross-covariance function $C_{pq}(n)$. σ^{2}_{p} is the variance of ultrasonic sensor p for the moment n, V^{2}_{p} is the error of true value and measured value. W^{*}_{p} is the optimal weighting factorof ultrasonic sensor p for the moment n . $\overline{X}_{p}(n)$ is the mean of ultrasonic sensor p for the moment n . $\overline{X}$ is the estimate vaule for the moment n.

Data fusion was realized by the interrupt handling procedure.Trigger condition is the sensor have received all the data, then, interrupt return values feedback to the robot self-protection software. The specific program flow chart is shown in Figure 4

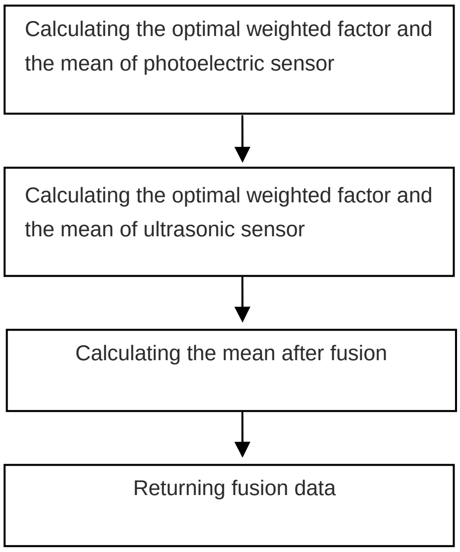

Figure 4. Data fusion subroutine software flow chart

3.2. Self-protection Function Software Realization

The whole robot self-protection functions are realized by the MCU software programming. System flow chart is shown in Figure 5.

According to different distance, the sensors are activated differently [4]. If the distance is less than 30cm, photoelectric sensor is given priority to; if the distance is more than 30cm,ultrasonic sensor is given priority to. Distance can be set through keying. Obstacle avoidance, highland judgment and dropping preventing functions can be completed by mutual cooperation of the two kinds of sensors.A timing cycle for 5ms interrupt cycle can be produced by MCU timer interrupt. By the timer interrupt function, the six photoelectric sensors will have a state scanning, to achieve real-time monitoring effect, to make adjustments timely. Without obstacle, MCU can’t measure any signal of photoelectric sensor, then the ultrasonic sensor will be triggered for obstacle detection.

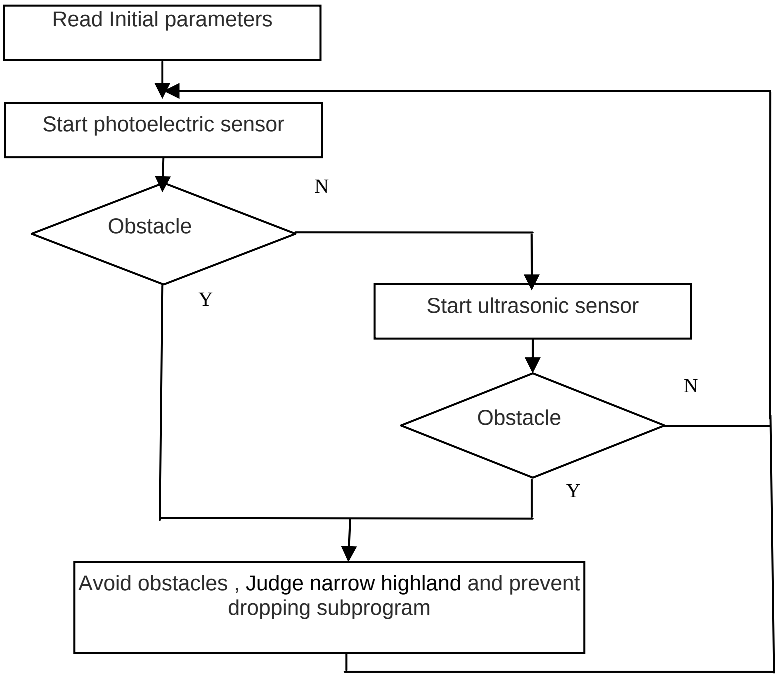

Figure 5. Robot self-protection flow chart

Three basic self-protection functions are introduced as follows:

(1) Avoid obstacles function

If the distance between the robot and obstacle ahead is more than given parameter of avoiding obstacles, robot will stop, and drive steering gear to adjust head angle and test.The robot will make the corresponding treatment after the testing data have been sent to the MCU and been processed.

Avoid obstacles block: First of all, steering gear will be turned to 170 degrees position (namely the head turns left) under control of MCU, trigger after sensors detect distance. Then the steering gear will be turned to 10 degrees position (namely the head turns right), trigger sensors detect distance. If the distances measured on left and right sides are both greater than given parameter, and left distance is greater than the right, then turn the left. If the right distance is greater than the left, then turn right, If the distance of measured both sides are less than given parameter, the robot turns back in order to avoid obstacles .The flow chart is shown as in Figure 6.

(2) Judge narrow highland function

The combined photoelectric sensor and ultrasonic sensor are used to judge whether there is object or not within the given distance. When the number of having signal sensors on robot track wheels is more than 3, the robot will make the judgment that it is in the narrow highland, it will halt and at the same time send relevant data to the MCU. The flow chart is shown as in Figure 7.

(3) Prevent dropping function

When the number of having signal sensors on robot track wheels is one or two, it will stop and judge the source of the sensor signals. Then according to the impending position, it willturn to the opposite direction and go straight. The flow chart is shown as in Figure 7.

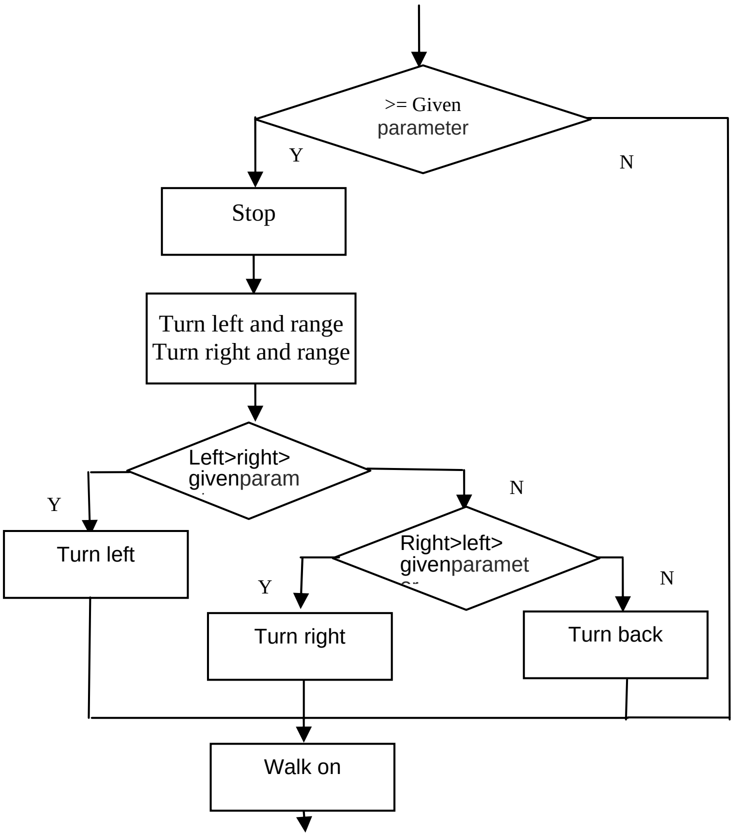

Figure 6. Avoid obstacles flow chart

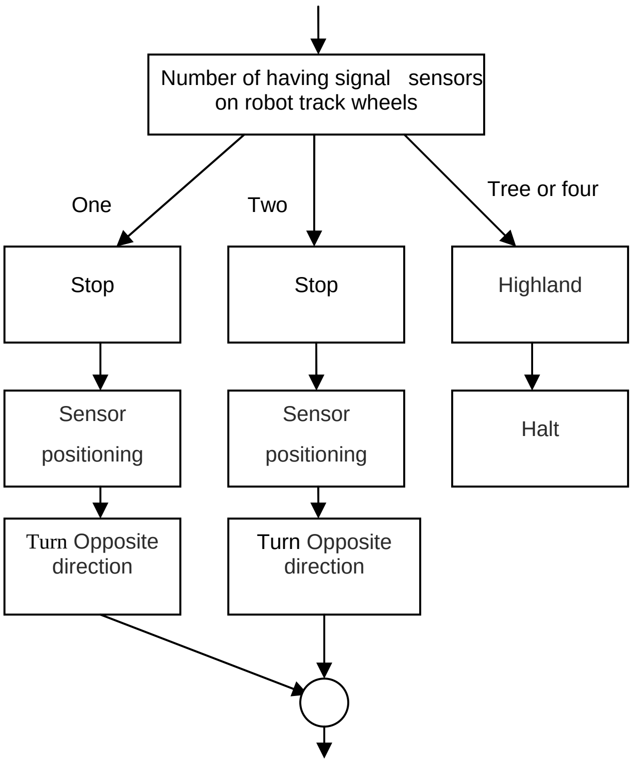

Figure 7. Judge narrow highland and prevent dropping flow chart

4. Conclusion

The experiment results show that: narrow highland judgment function and highland dropping preventing function can achieve 100%, the robot can halt accurately to achieve self-protection.

The ranging accuracy of avoiding obstacles in 0.5-400cm will be 1%. In less than 30cm of ranging, the distance detection can be completed by photoelectric sensors, while in 30-400cm the distance detection can be completed by ultrasonic sensors. Experimental results can be seen from Table 1.

Table 1 Experimental results

Setting distance cm	Actual avoid distance cm	Error rate %	Setting distance cm	Actual avoid distance cm	Error rate %
10	10.09	0.98	150	151.06	0.71
20	20.18	0.90	200	201.52	0.76
30	29.78	0.80	250	251.90	0.76
40	40.32	0.80	300	302.50	0.83
50	50.50	1.00	350	352.20	0.63
100	100.80	0.80	400	403.52	0.88

This paper studies a kind of low-cost, low-power consumption, high efficiency self-protection system of mobile robot. By the combination of photoelectric sensors and ultrasonic sensors, the problem of single sensor ranging blind spot can be effectively solved. With 6 group sensors installed in different positions, the robot can complete five different azimuth detection tasks. The experiment results validate its good self-protection function.

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